Seattle's Cascadia Subduction Zone Seismic Hazard: Potential Impact on Buildings

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The Power of Earthquakes

Photo posted to Reddit, taken minutes after the February 2011 Christchurch, New Zealand Earthquake

Earthquakes Don't Kill People: Buildings Do

Christchurch, New Zealand

Christchurch, New Zealand

Intent of Modern Building Codes

To Prevent This!

Kobe, 1995 (Photo: PEER)

- Collapse prevention
- Large and infrequent earthquakes
  - 2500 year return period
  - 2% probability in 50 years
- Significant damage expected
- Not considered:
  - Performance in more frequent earthquakes
  - Repair or replacement

Expected Performance

Reinforced concrete shear wall under construction in Seattle

Reinforced concrete shear wall damage from the 2010 Maule Chile Earthquake

Unacceptable Performance: Unpredictable and Brittle

Damage from lateral forces results in inability to carry gravity loads

Lyttelton Timeball Station: Damaged during the 2011 Christchurch, NZ earthquake
(Sarah Ivey / New Zealand Herald, via AP)

Seismic Hazard in the Pacific Northwest

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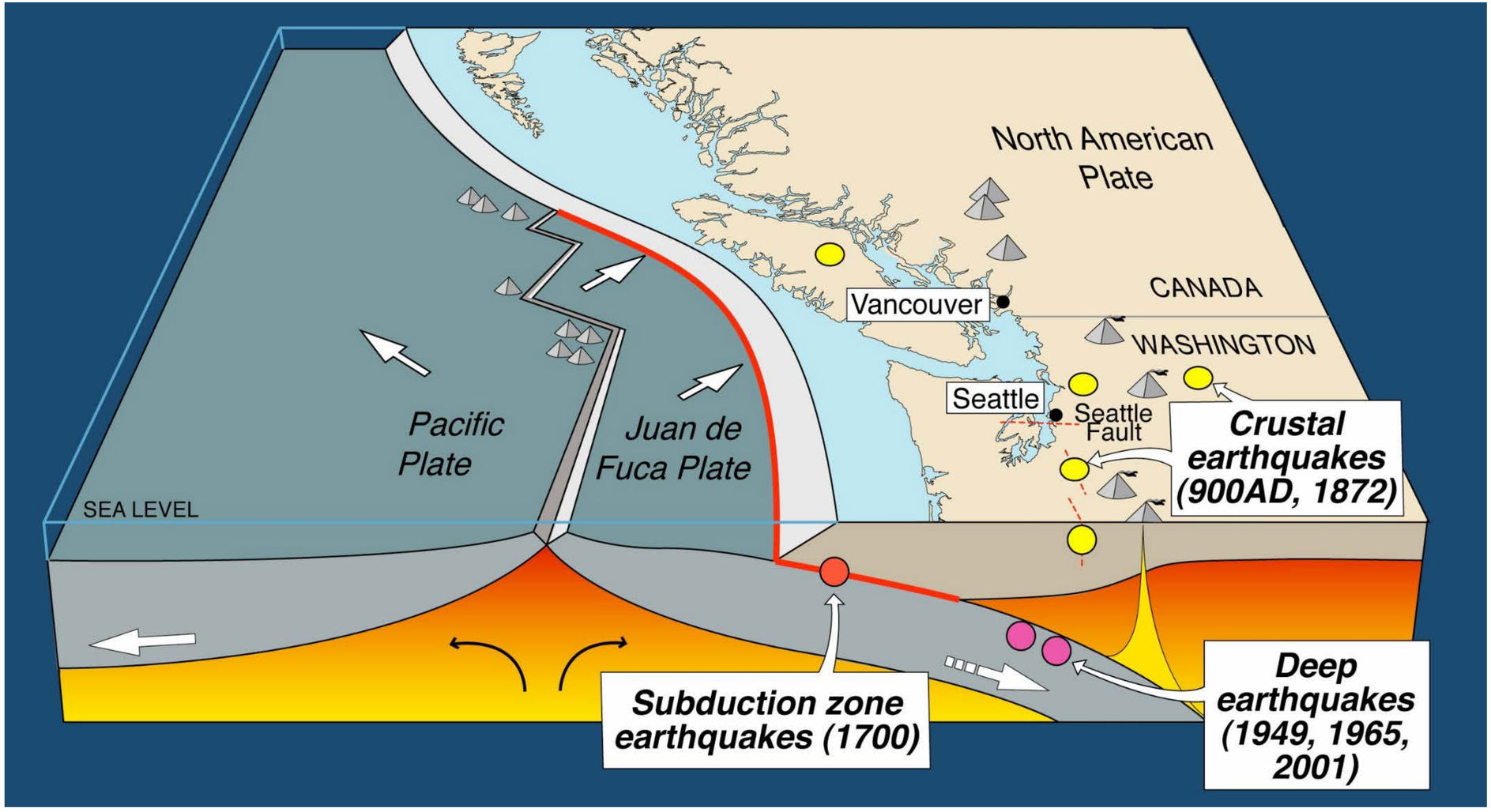
Plate Tectonic Setting

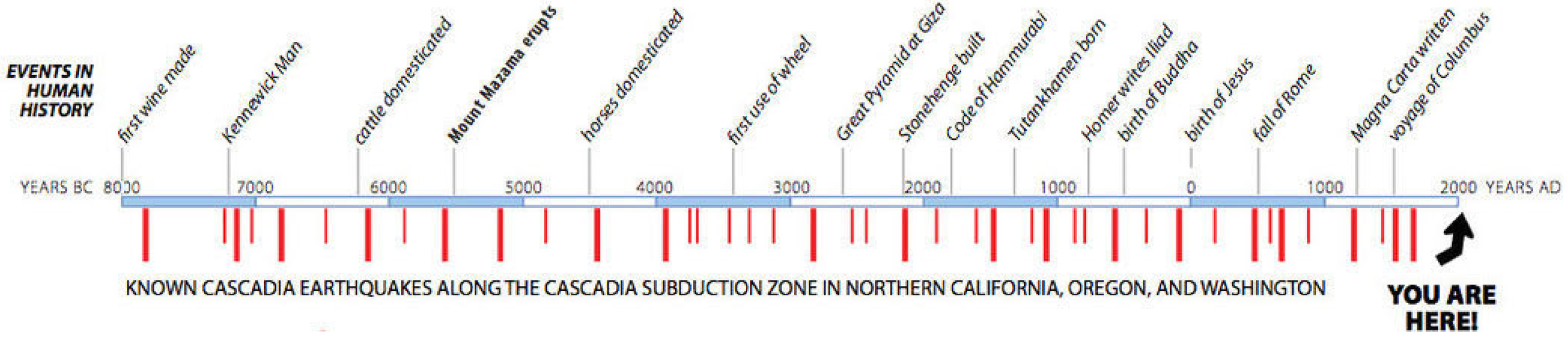
Cascadia subduction zone and Seattle fault threats not recognized until 1980s

I-5 through Seattle opened in 1967



(From USGS)

Last 10,000 Years: 20 M9 Events +20 M8 to 8.5 Events
(from Offshore Geology)



(Goldfinger et al., 2008, Bull, Seis. Soc. Amer)

- 10-20% probability of a Cascadia M9 in the next 50 years
  - On average, every 500 years
- 25-40% probability of a Southern Cascadia M8+ in the next 50 years

In the news…

THE NEW YORKER

ANNALS OF SEISMOLOGY | JULY 20, 2015 ISSUE

THE REALLY BIG ONE

An earthquake will destroy a sizable portion of the coastal Northwest. The question is when.

BY KATHRYN SCHULZ

Paints a dire picture…..

What will the impact be?

The M
Proje

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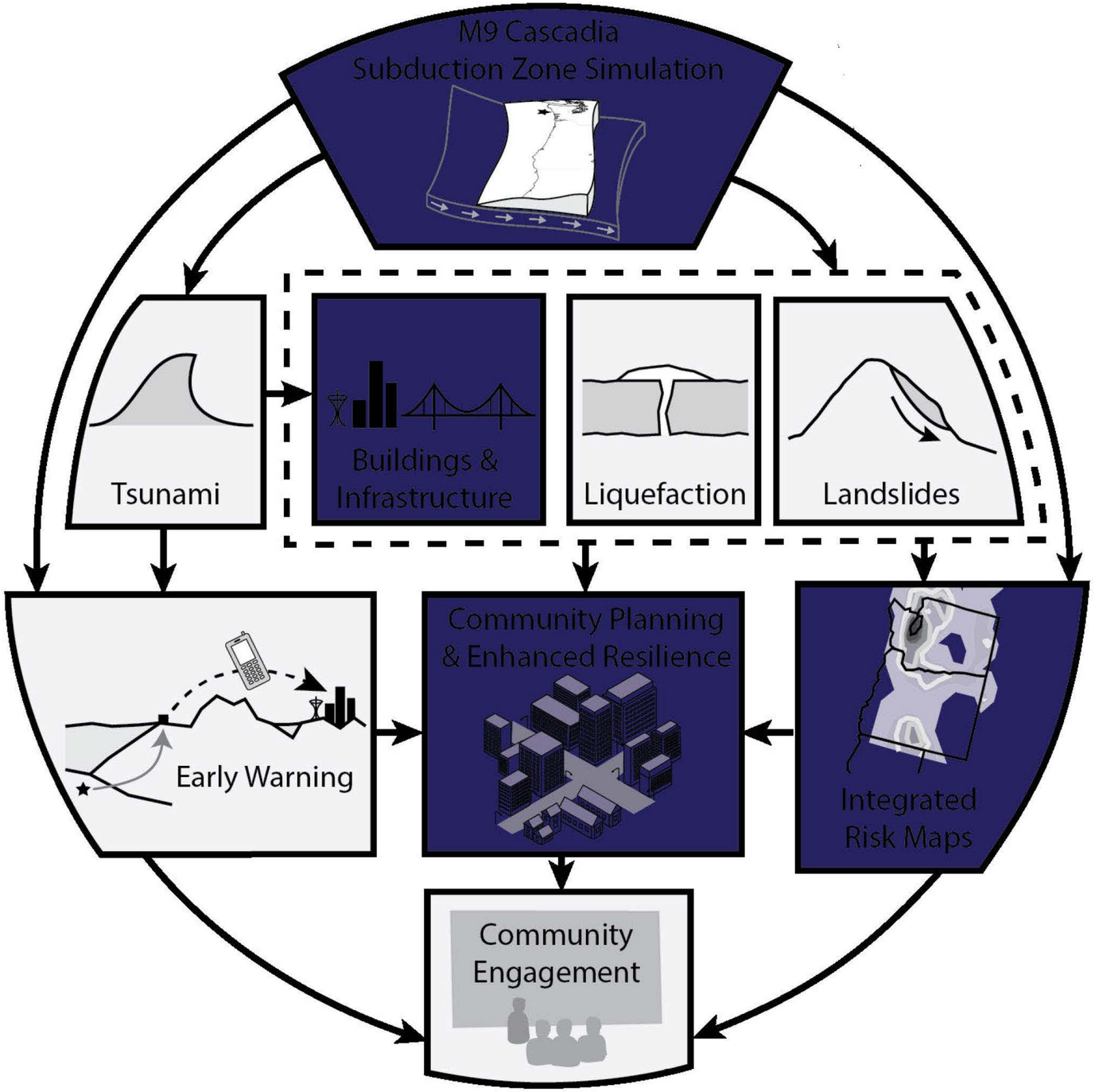
1 Post-Doc



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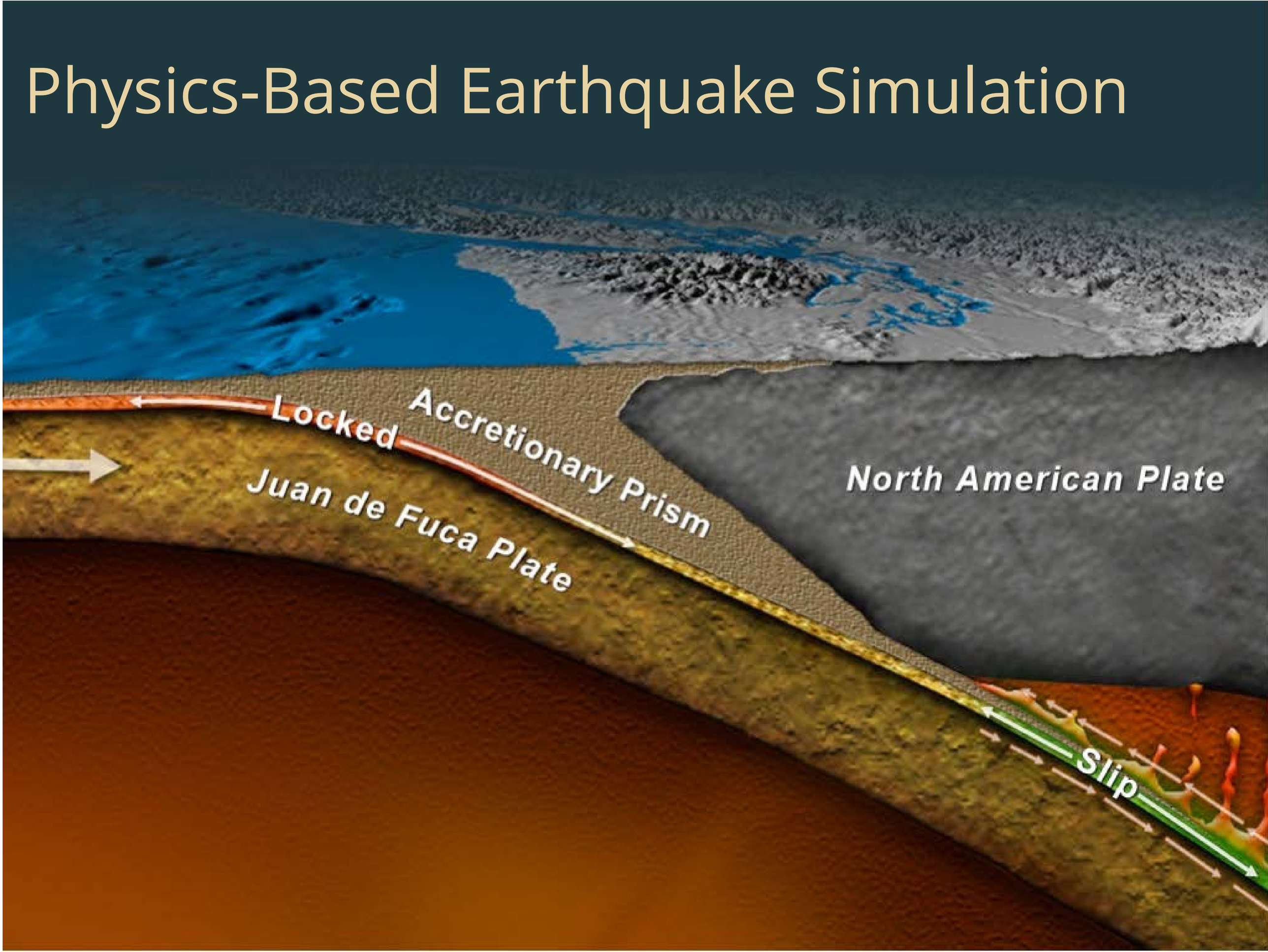
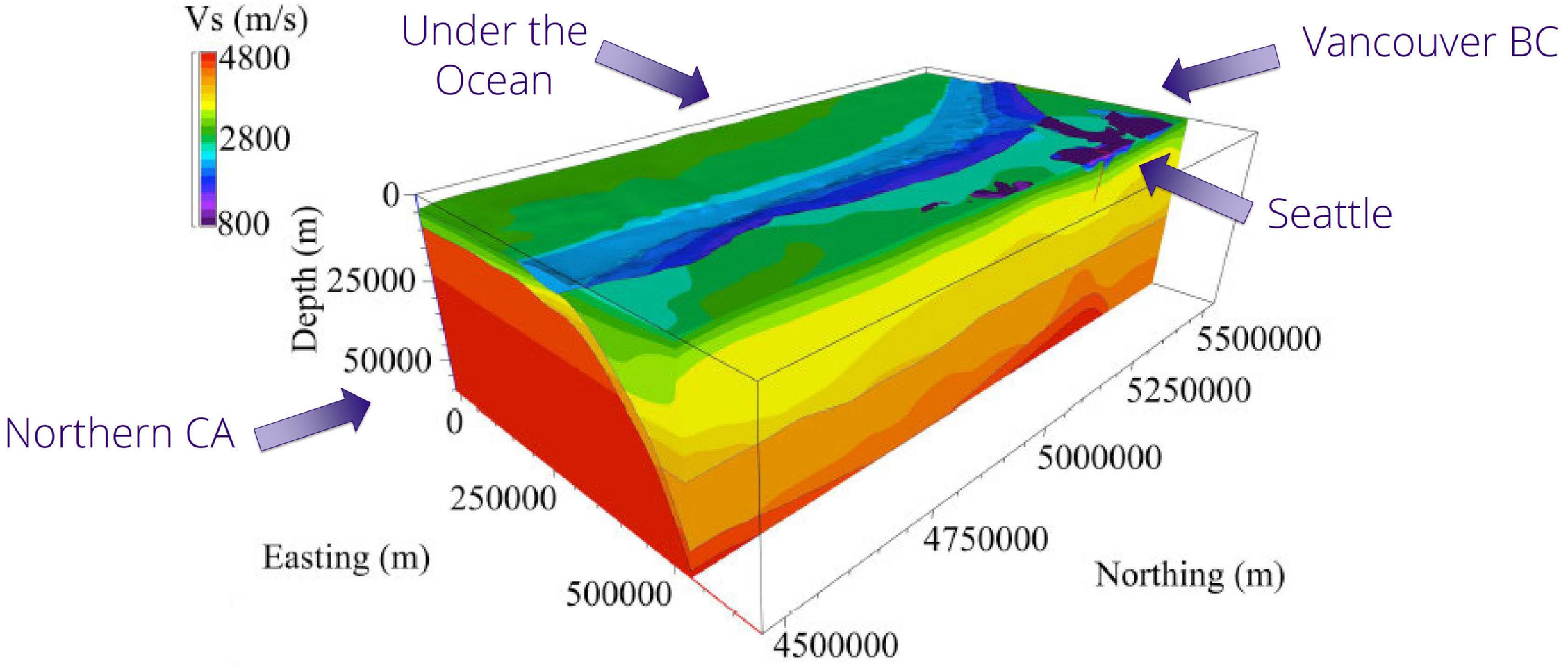
Space Sciences
ol of Public Policy
gn and Planning
athematics

NSF Hazards SEES
EAR-1331412

Physics-Based Earthquake Simulation



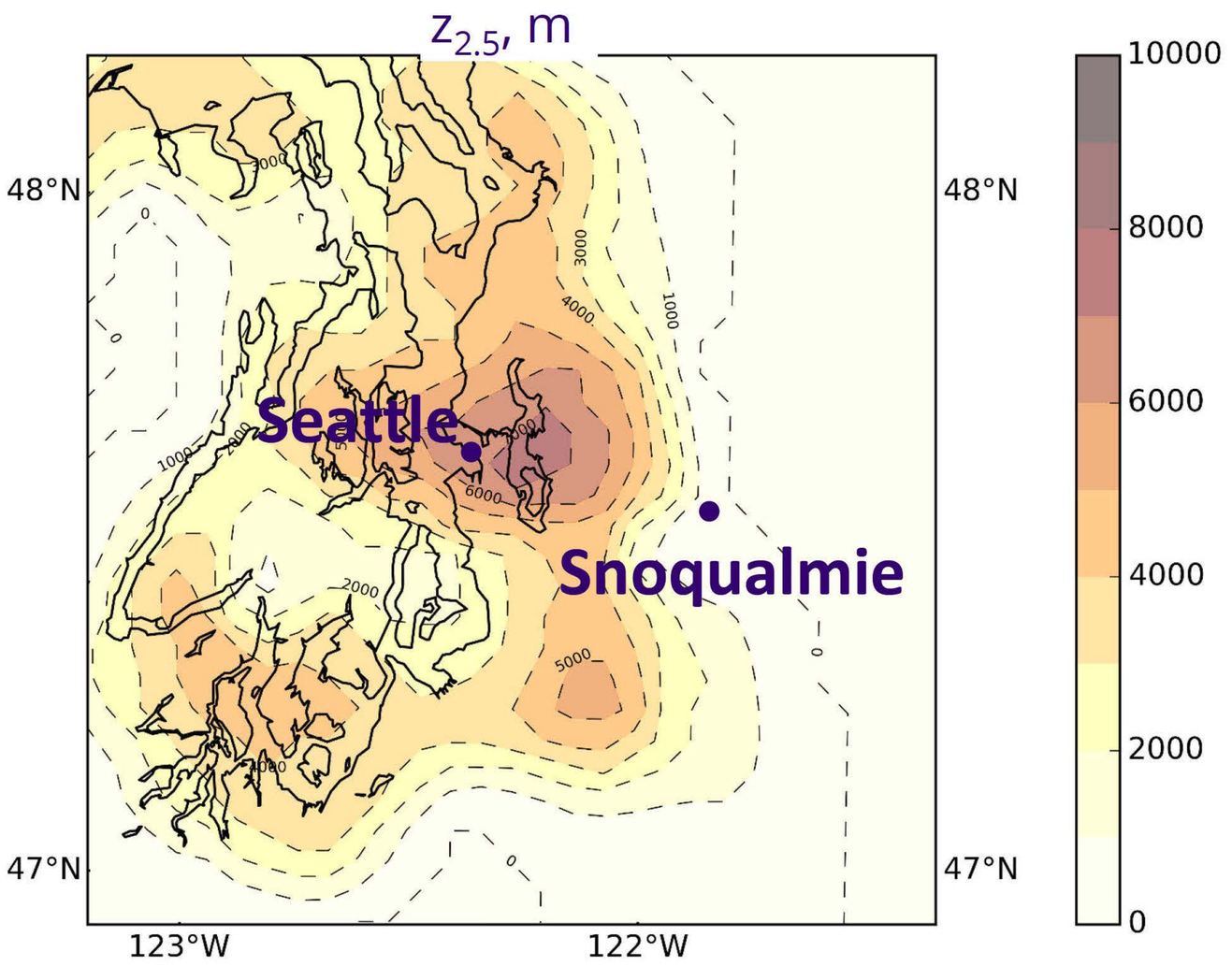
Physics-Based Modeling of Cascadia (USGS, Frankel)



(From seismic refraction/refraction data, Delorey and Vidale (2011) noise correlation model for Seattle basin, Moschetti et al. (2010) regional Vs, McCrory et al. plate interface.)

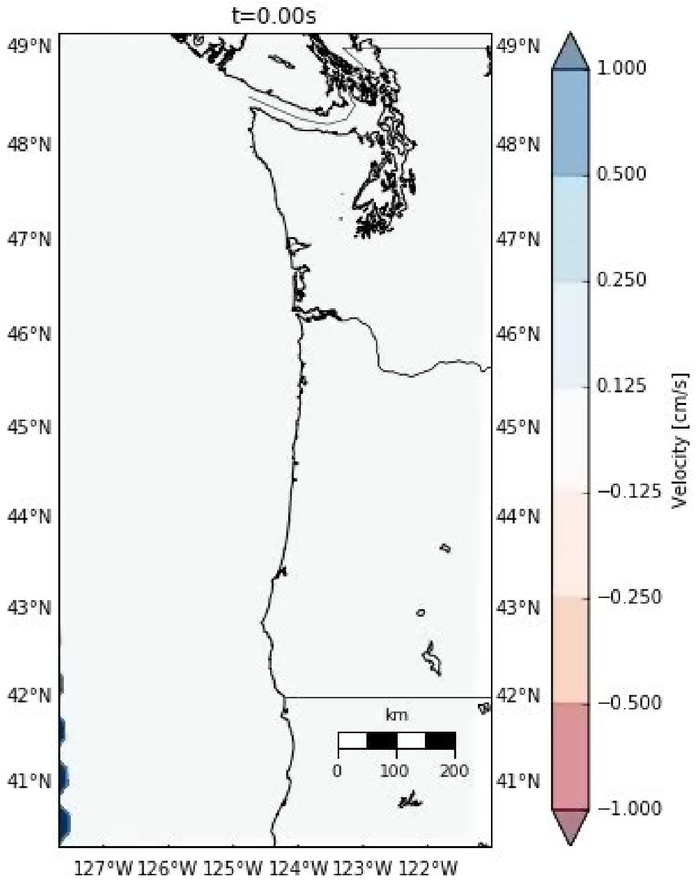
Seattle Basin

$z_{2.5}$ ≈ Depth to Rock



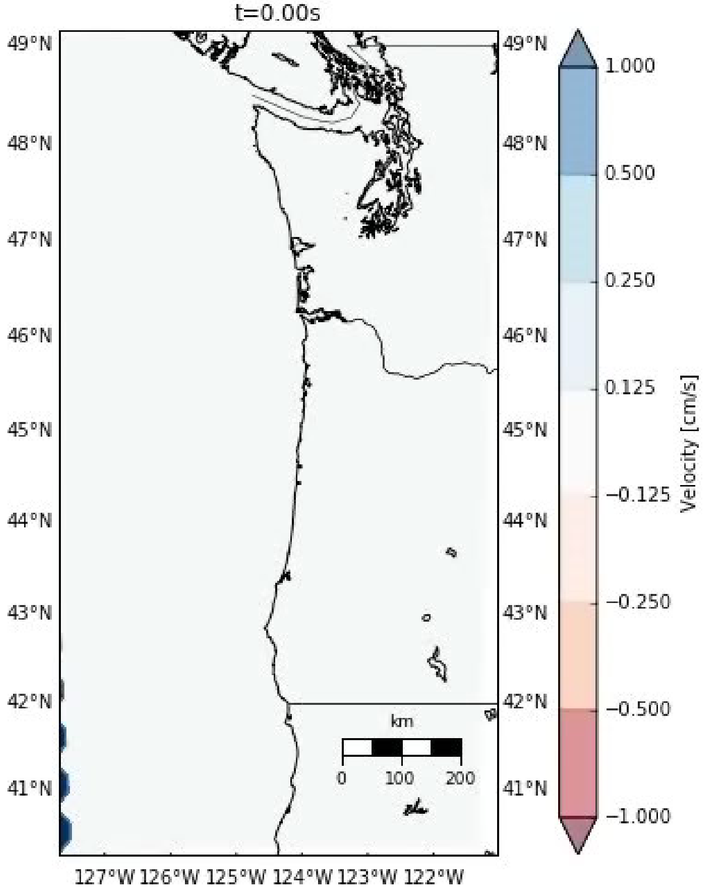
Two Simulations

Realization #1



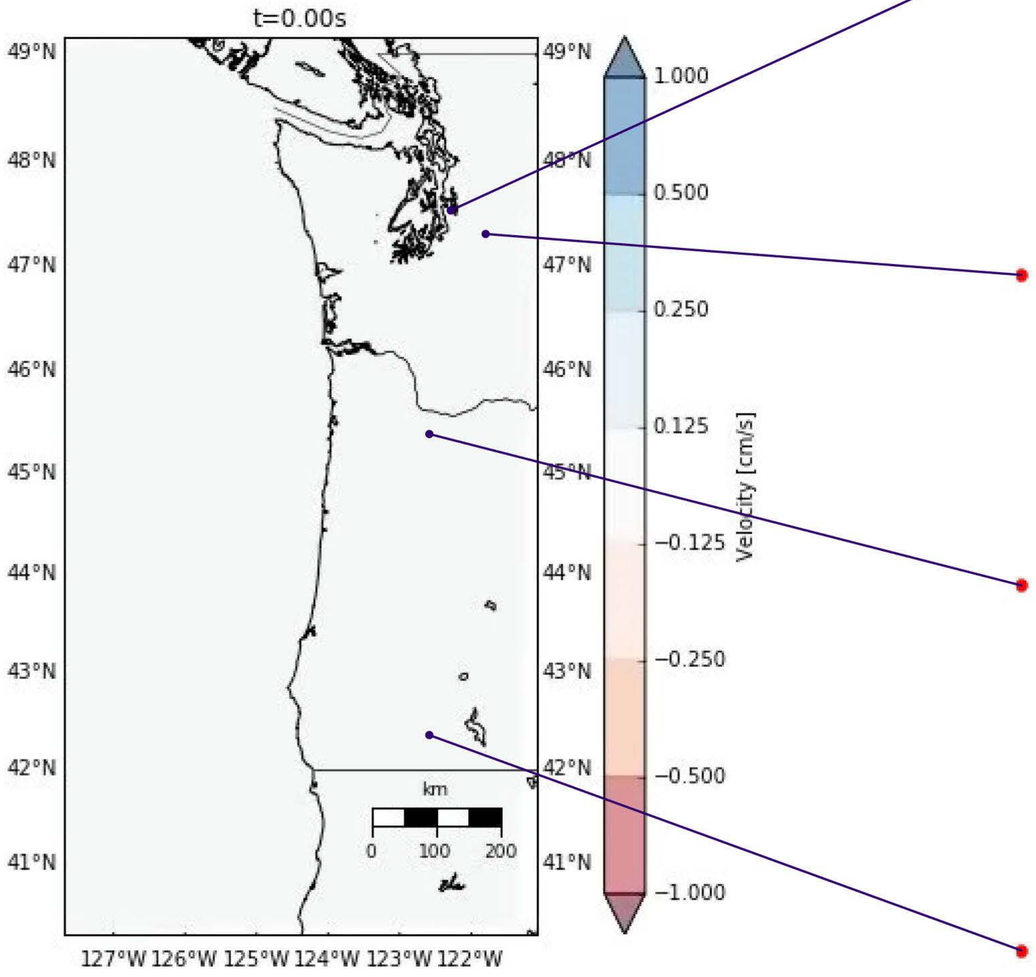
Off the OR Coast
Towards Seattle

Realization #2



Off S. OR Coast
Towards Seattle

Simulation Results: Ground Acceleration Histories



Seattle

Snoqualmie

Portland

Medford

How is it Different: Duration

Crustal
(1994 Northridge EQ)

M9 – Subduction
(In Seattle)

Longer Durations

Smaller Peak Ground Acceleration

Why it Matters:

Longer Duration

↓

Larger Number of Cycles

↓

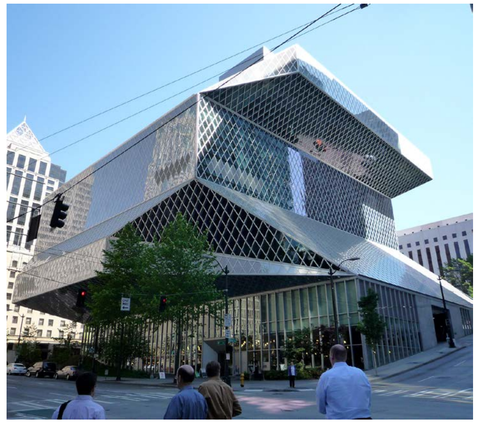
More Damaging

Building Periods: Related to Height

~2.0 Seconds

1 Story

0.1-0.4 Seconds



4 Story

0.5 Seconds

10-20 Story

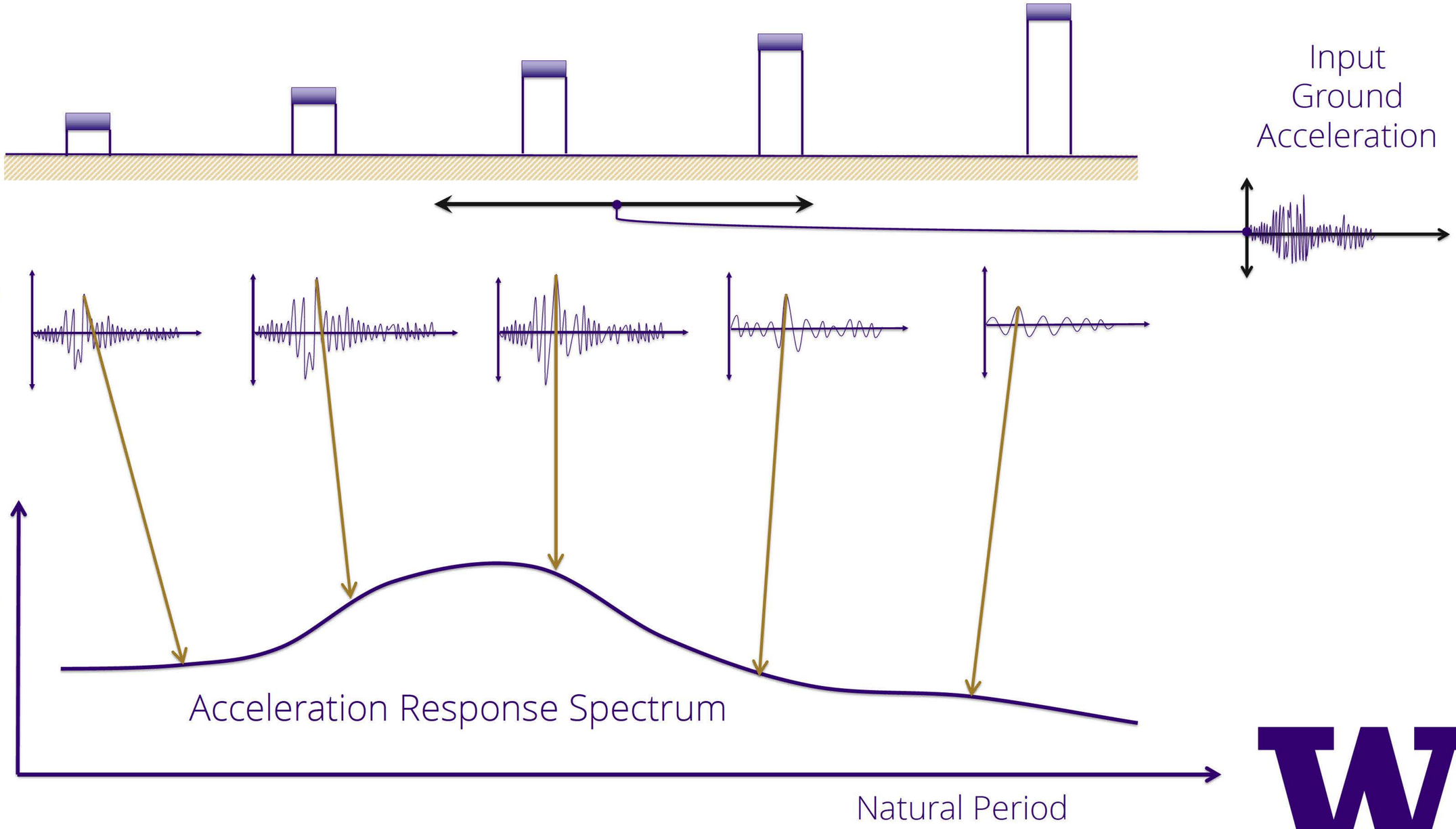
1.0-2.0 Seconds

~60 Story

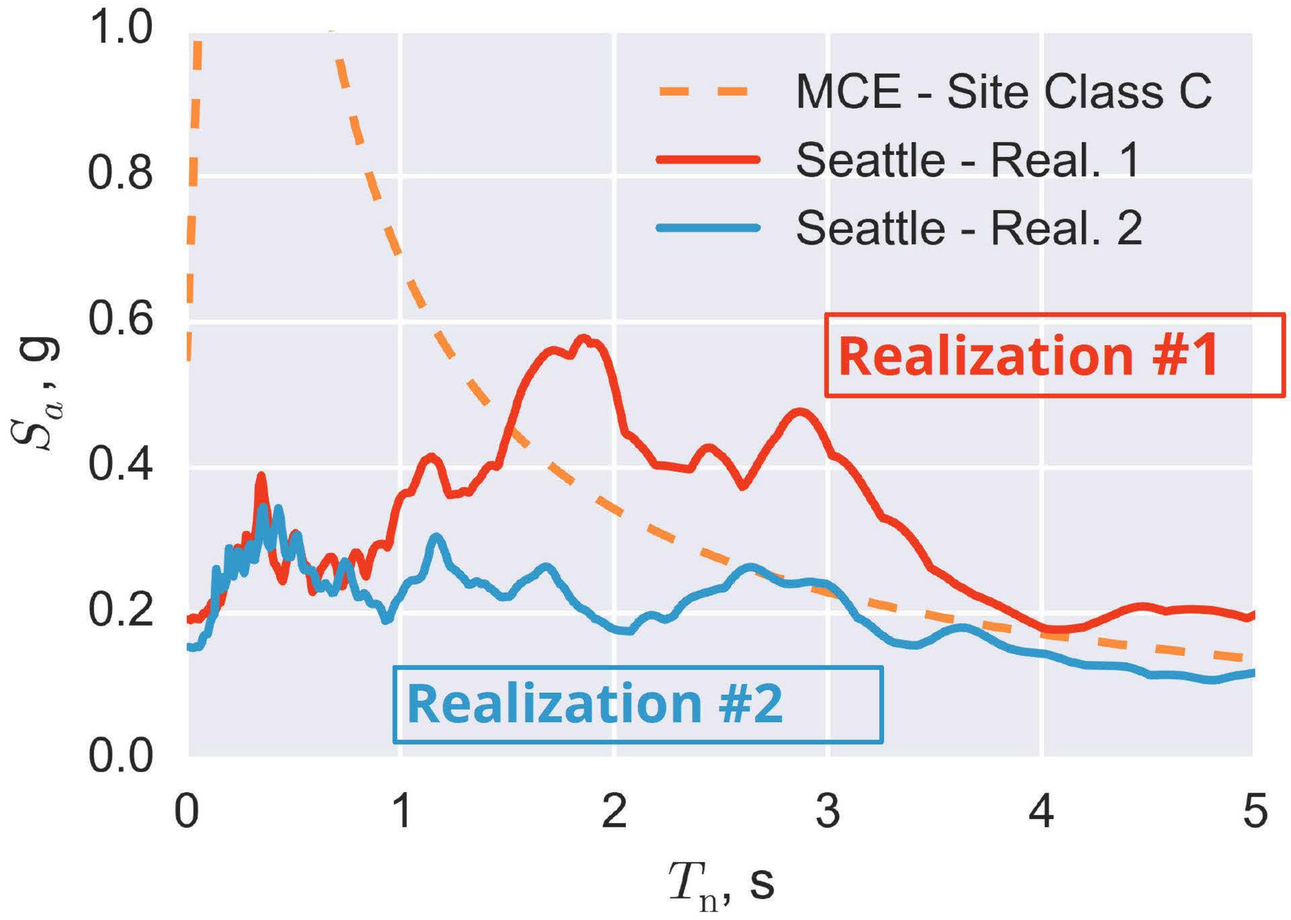
7.0 Seconds

When buildings are damaged their period gets longer

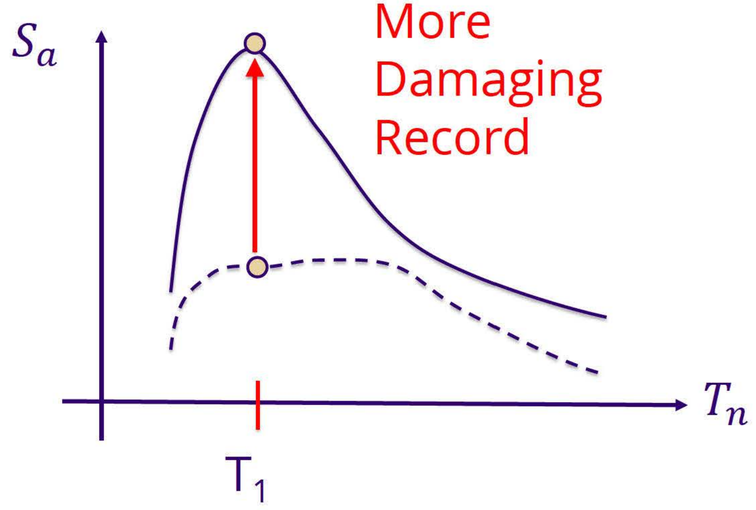
How is it Different: Spectral Acceleration

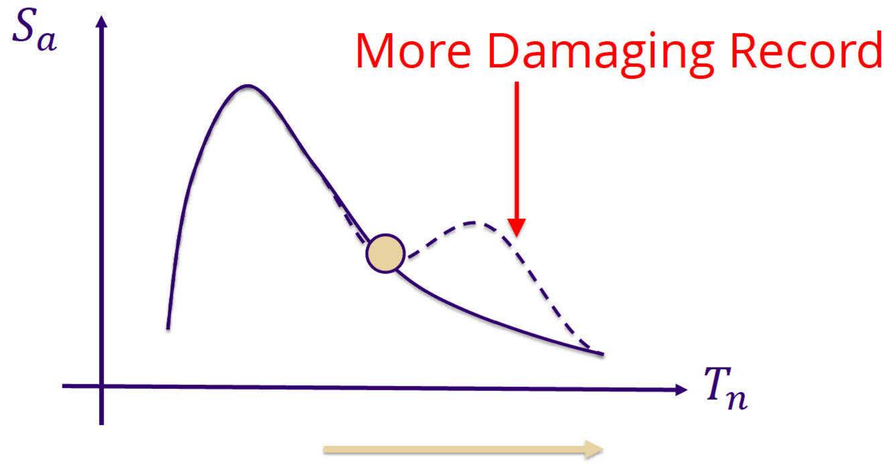


Acceleration Response Spectra



What it Means:





Softening Structures
(i.e., Structures with Damage)

Structural Response in Cascadia

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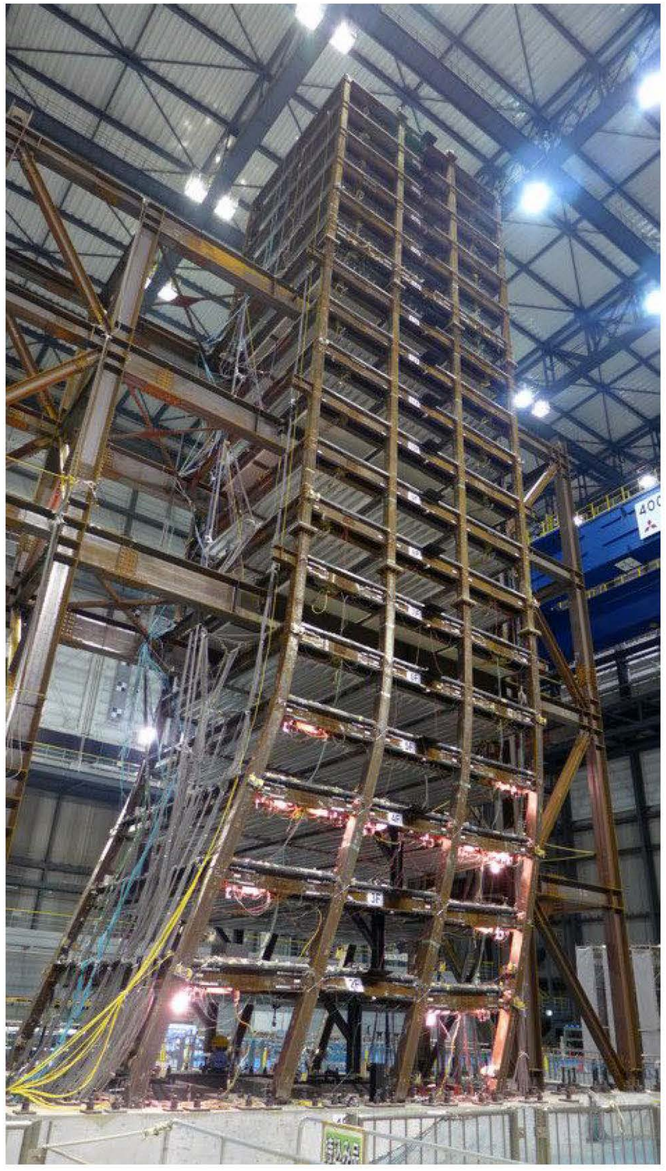
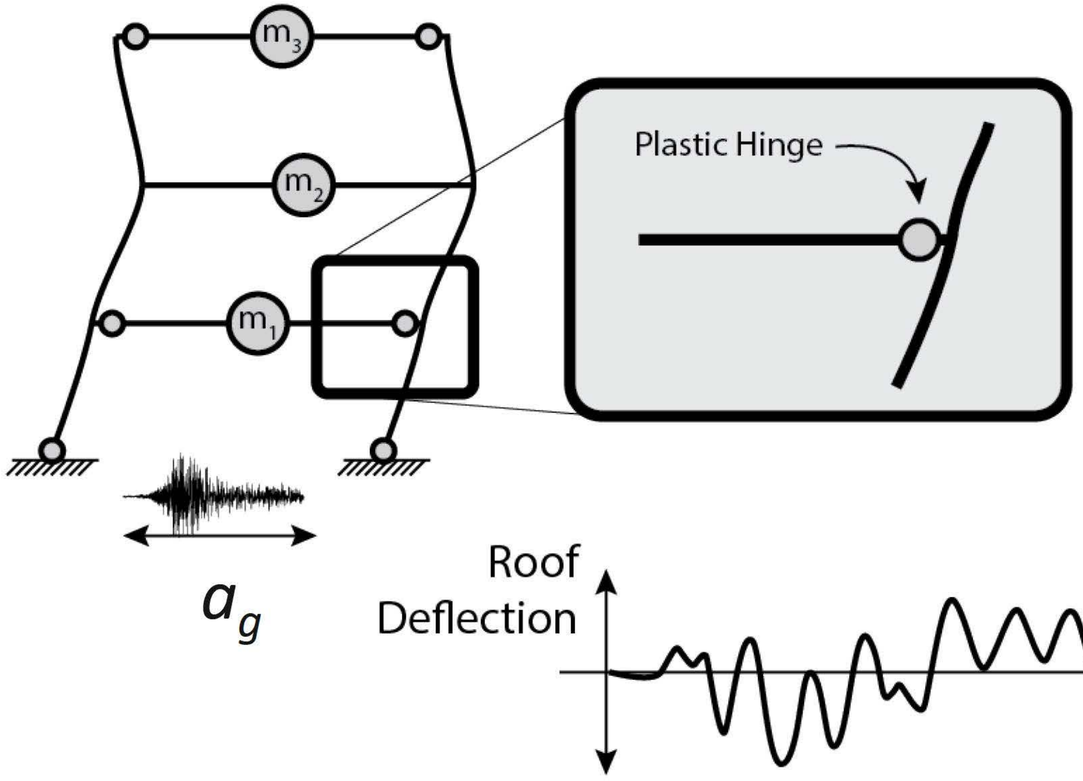
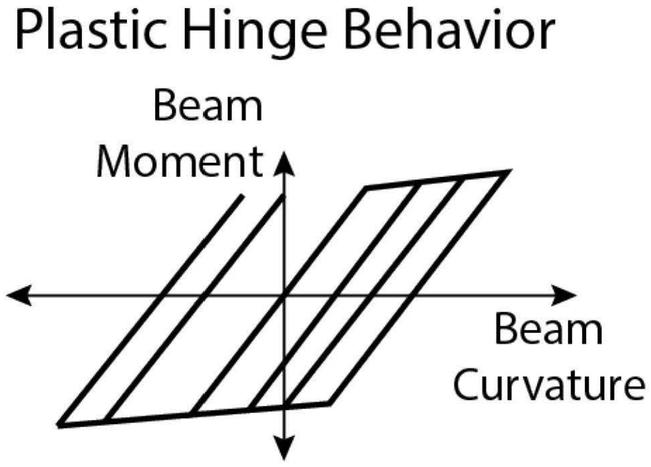
What the Building Shaking Looks Like

Numerical Modeling of Buildings







Comparison of Building Response: Short Period

Northridge
(Scaled to MCE)

Snoqualmie
(Outside Basin)

Seattle
(Inside Basin)

Max. Interstory Drift: 1.3%

Max. Interstory Drift: 0.4%

Max. Interstory Drift: 0.4%

T_n = 0.52s

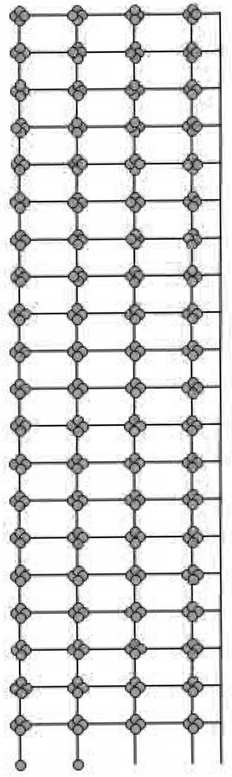
Exaggerated Horizontal Deflections (x10)

Comparison of Building Response: Long Period

Northridge
(Scaled to MCE)

Snoqualmie
(Outside Basin)

Seattle
(Inside Basin)



Max. Interstory Drift: 1.0%

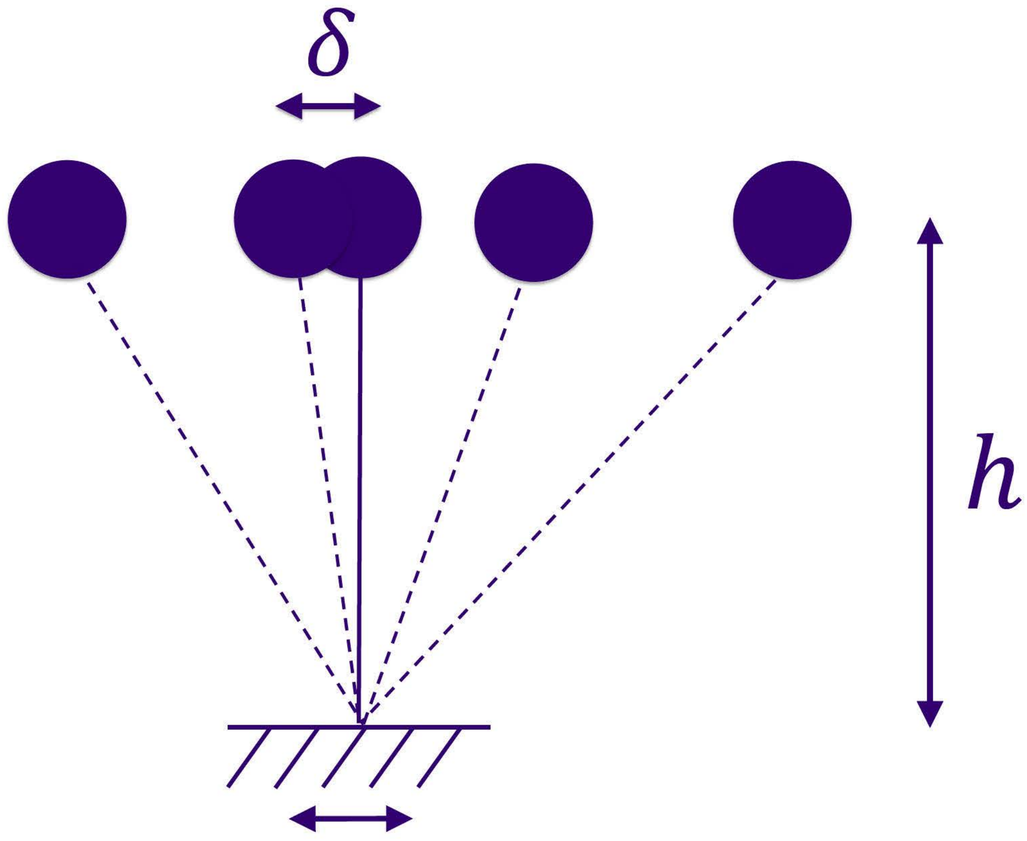
Max. Interstory Drift: 0.2%

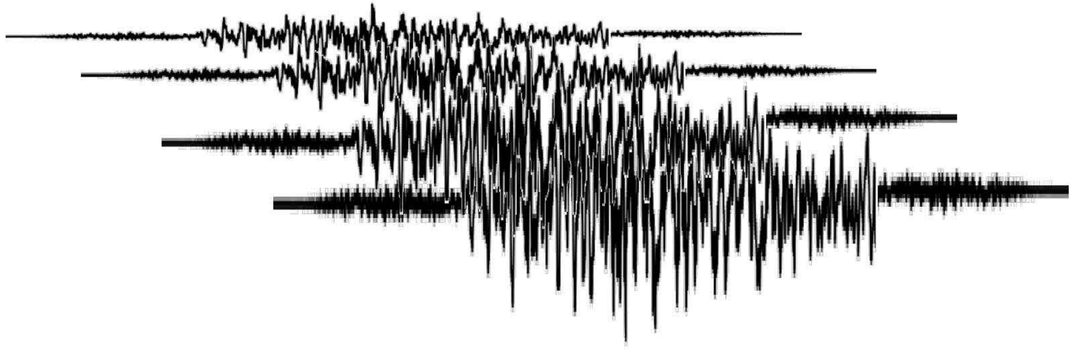
Max. Interstory Drift: 4.0%

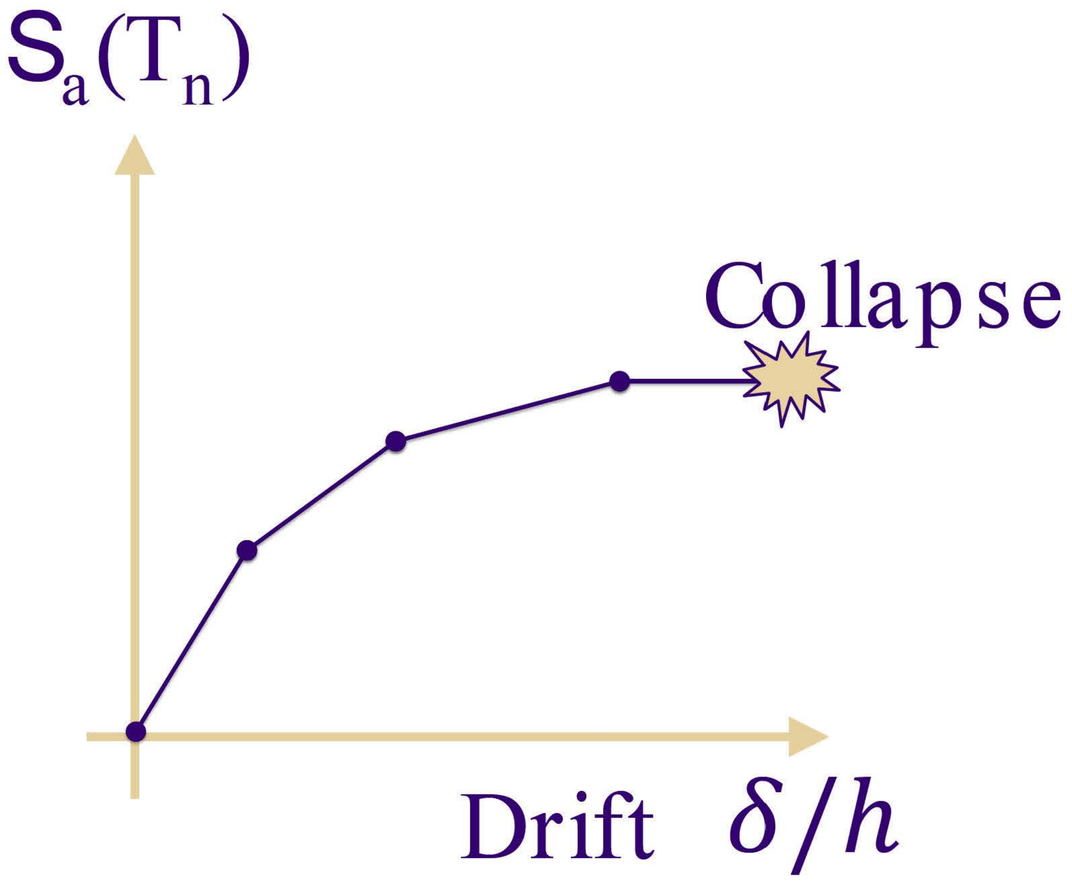
T_n = 2.5s

Exaggerated Horizontal Deflections (x10)

Estimating Collapse Intensity

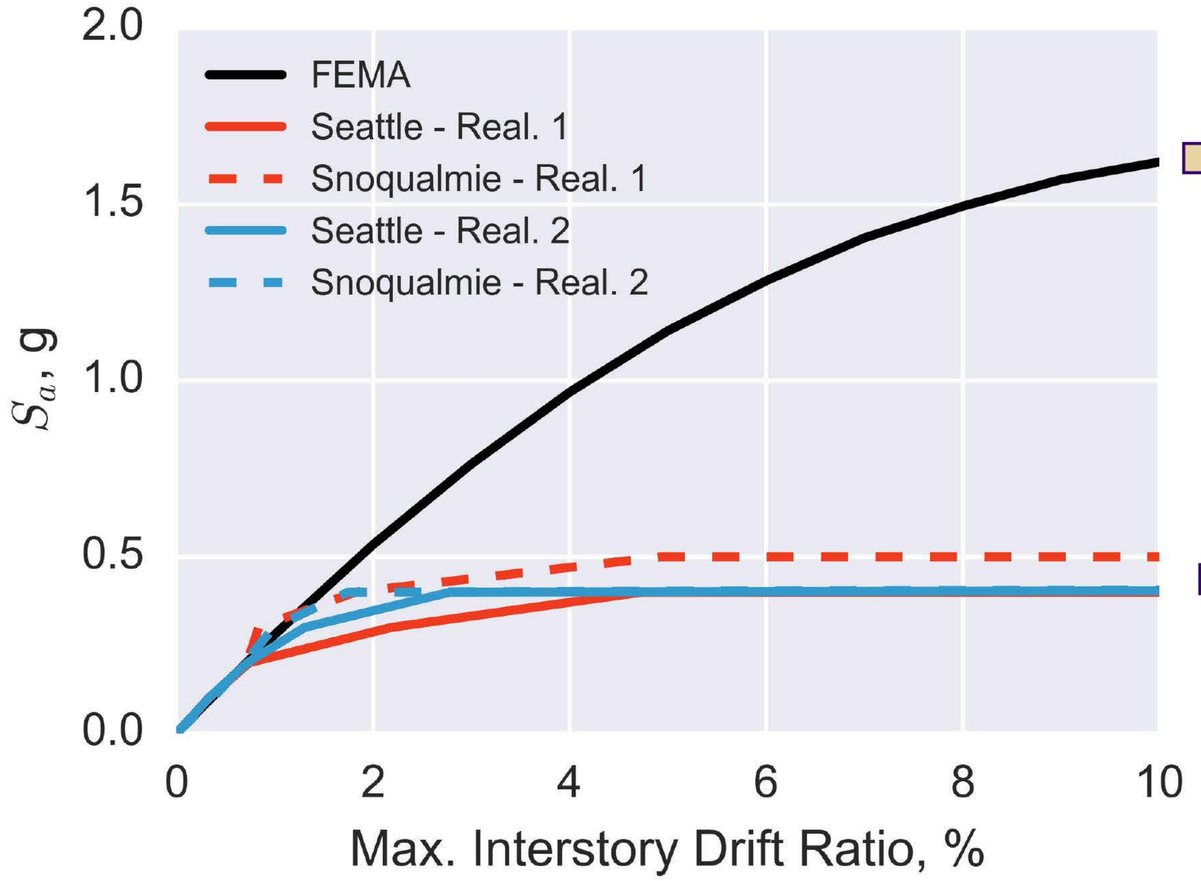






Collapse In M9 CSZ?

- 4 Story Reinforced Concrete Building
- Natural Period ~1.0 sec.



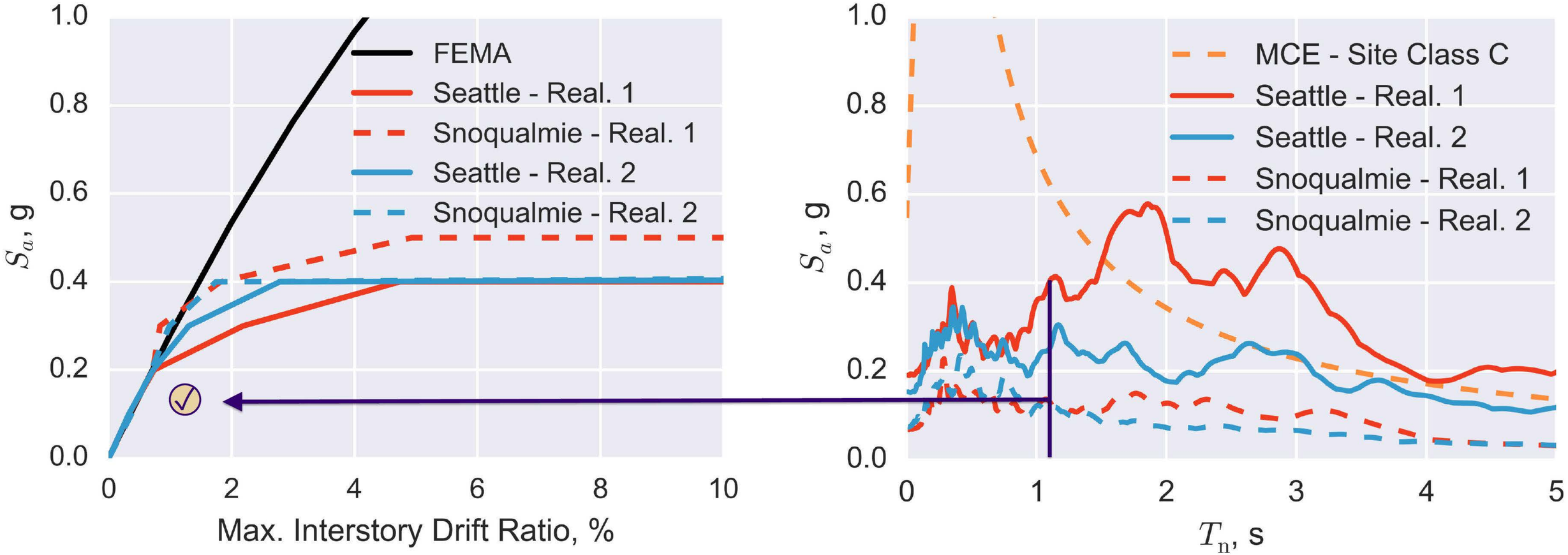
Crustal (CA) ground motions: Collapse at 1.65g

Cascadia ground motions: Collapse at less than 0.5g

Why is the performance of the same building so much worse for Cascadia shaking?

Duration and period content

Collapse In M9 CSZ?



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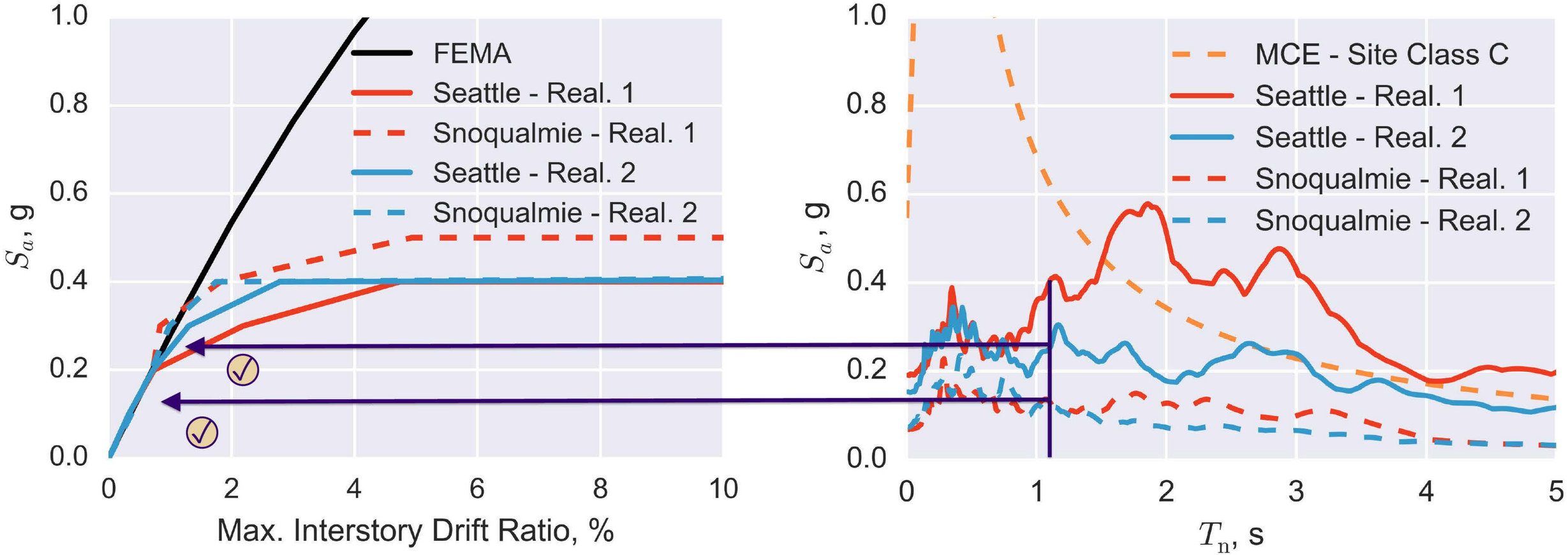
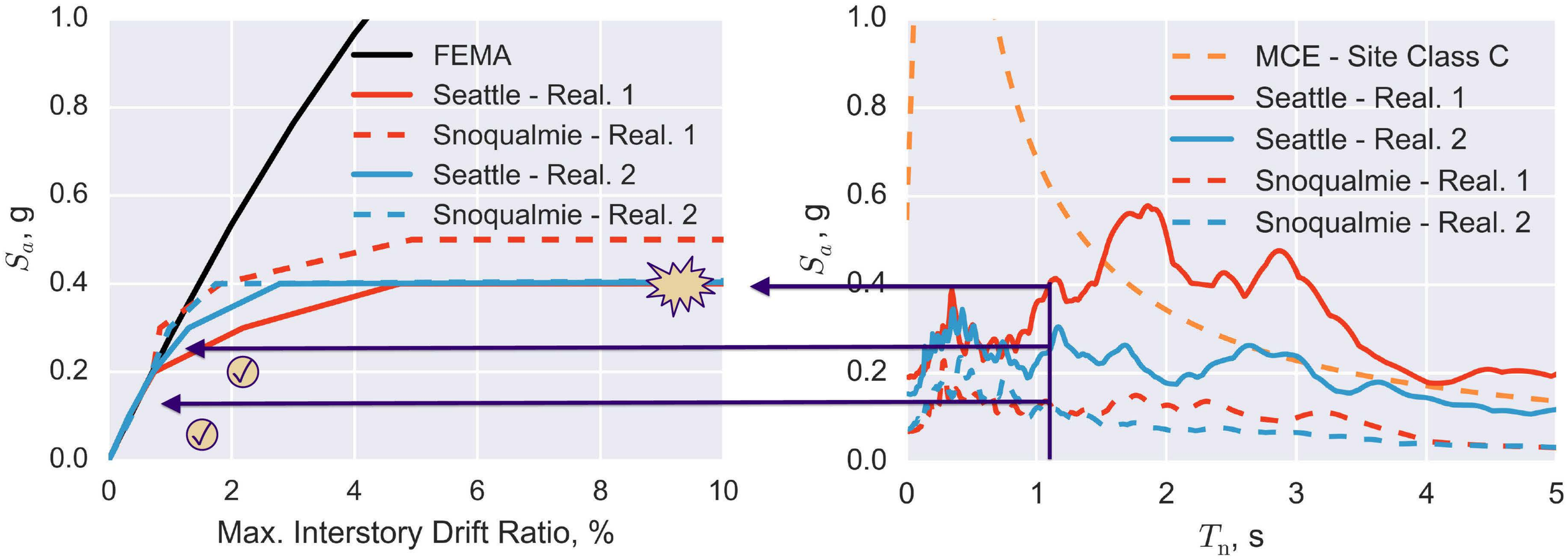


Collapse In M9 CSZ?

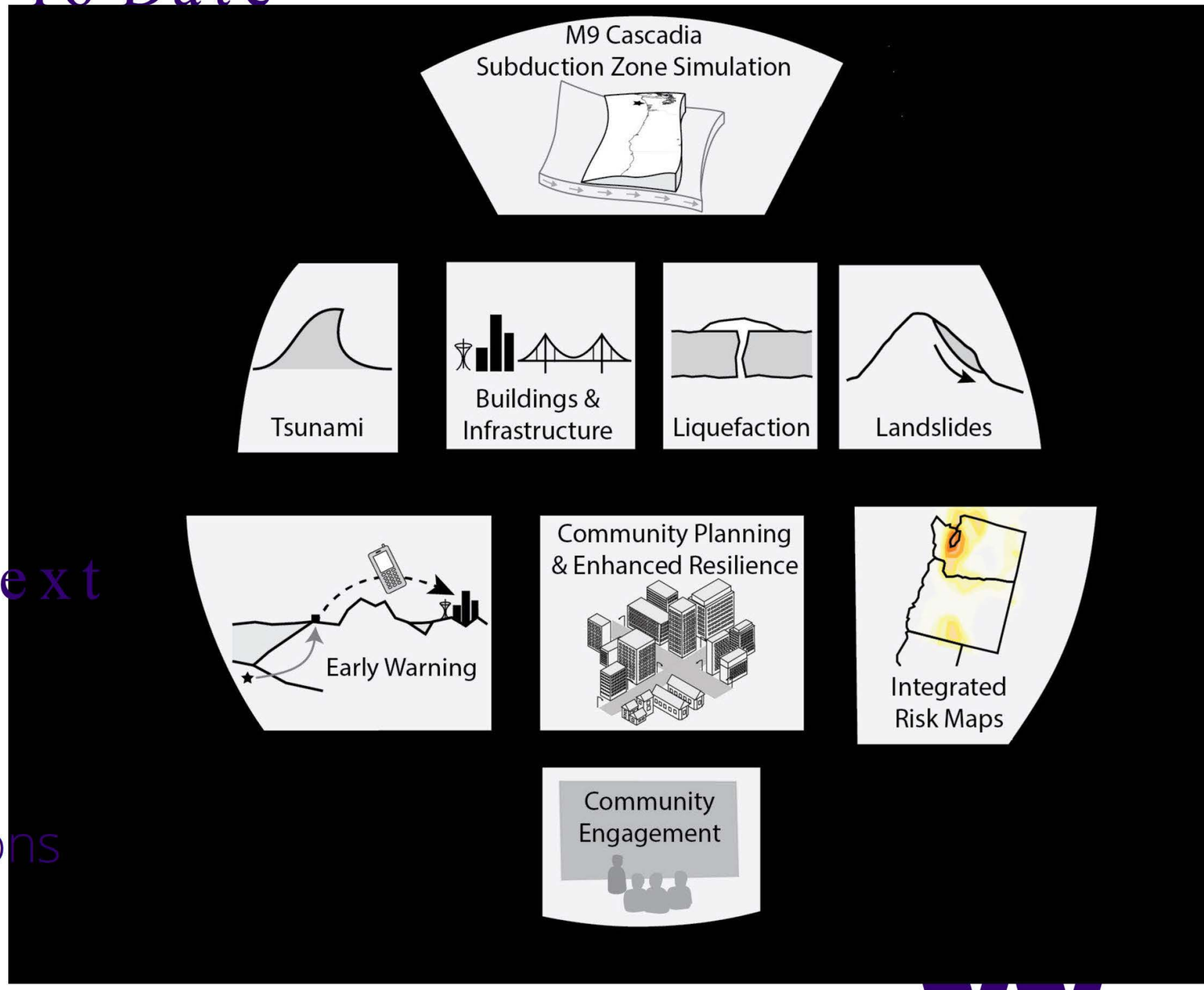


M9 Project: Findings To Date

- Ground motions:
  - Long duration
  - Basin amplification
  - Considerable variability
- Concerns: structures with T_n > 1.0 sec

M9 Project: What's Next

- 100 M9 simulations
- Typical Seattle buildings
- Building code recommendations



Closing Thoughts

Are We Prepared?

Seismic Evaluation and/or Retrofit Requirements (City and State)

	San Francisco	Los Angeles	Seattle
Hospitals	Yes	Yes	No
Schools	Yes	Yes	No*
Unreinforced Masonry Buildings	Yes	Yes	No
Nonductile Concrete Buildings	No	Yes	No
Soft-Story Timber Buildings	Yes	Yes	No

* No legislation but evaluations have been conducted by SPS

Unreinforced Masonry Italy, 2016

Nonductile Concrete Christchurch, 2010

Soft-Story Timber Northridge, CA 1994

What We Know

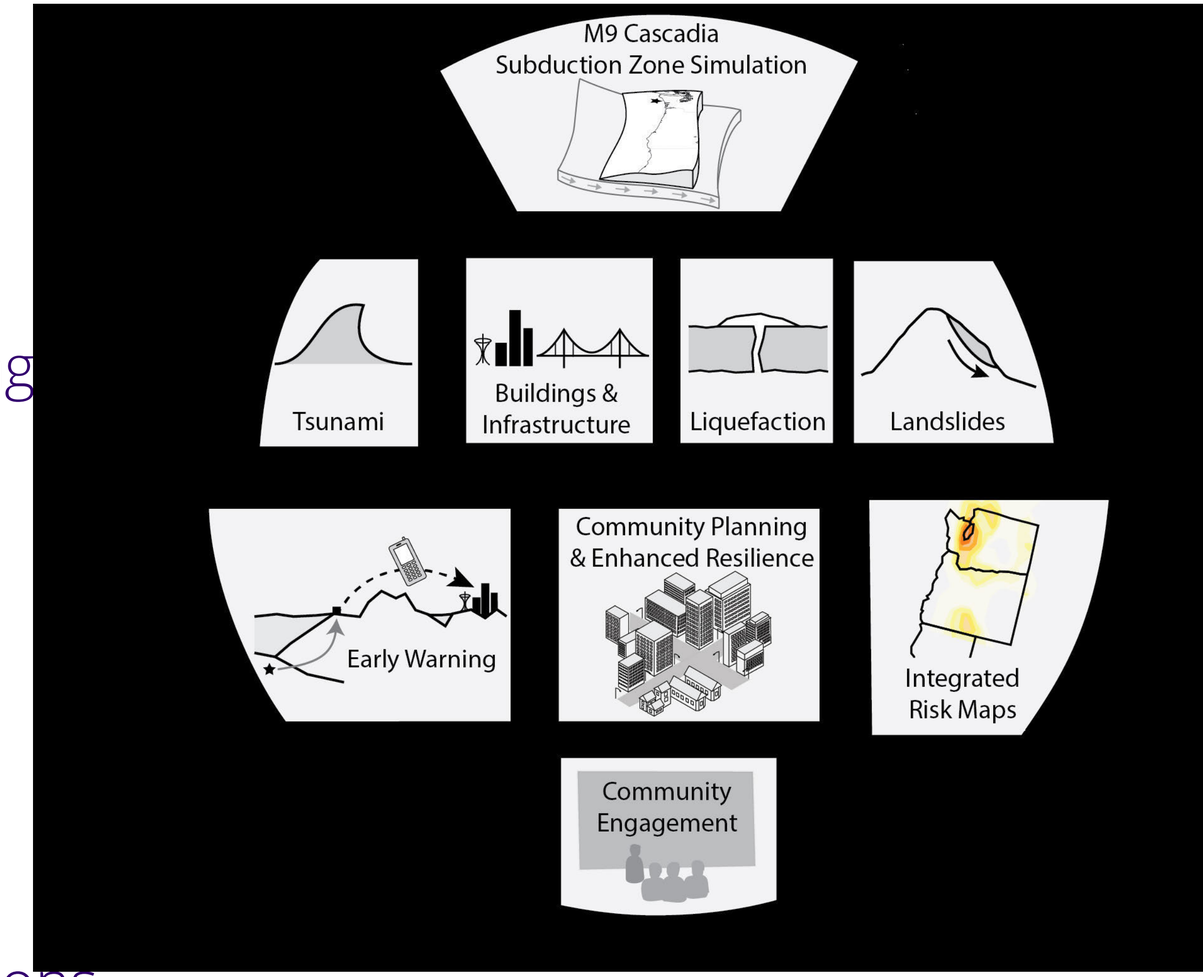
- Significant seismic hazard in PNW
- Infrequent but high-consequence events
- Cascadia subduction zone events and regional geology produce unique issues
- Our infrastructure is old
- Resilience requires an interdisciplinary approach
- Engineering solutions can help:
  - Making buildings stronger is not the only solution
- Much more to do

Concrete Shear Wall Damage from the 2010 Maule Chile Eqarthquake
Photo From Dawn Lehman, UW

UW Can Help

> Experts in:
  - Seismology
  - Structural and geotechnical engineering
  - Coastal science and engineering
  - Urban planning
  - Emergency response and recovery
  - Public policy

> We can:
  - Advocate for action towards resilience
  - Perform research to answer key questions
  - Pursue funding mechanisms for collaborative efforts



Acknowledgements

- Collaborators and Colleagues
  - Marc Eberhard, Dawn Lehman, Laura Lowes, Paolo Calvi, Art Frankel, John Vidale, Steve Kramer, rest of the M9 Team
- Graduate Students
  - Nasser Marafi (M9), Ryan Ganey (Timber Walls), Andy Sen (Braced Frames)
- National Science Foundation, USGS
- UW, the College of Engineering and the Department of Civil and Environmental Engineering

Damage from the 2001 Nisqually Earthquake

Thank You!

Cyprus Viaduct Collapse in 1989 Loma Prieta Earthquake

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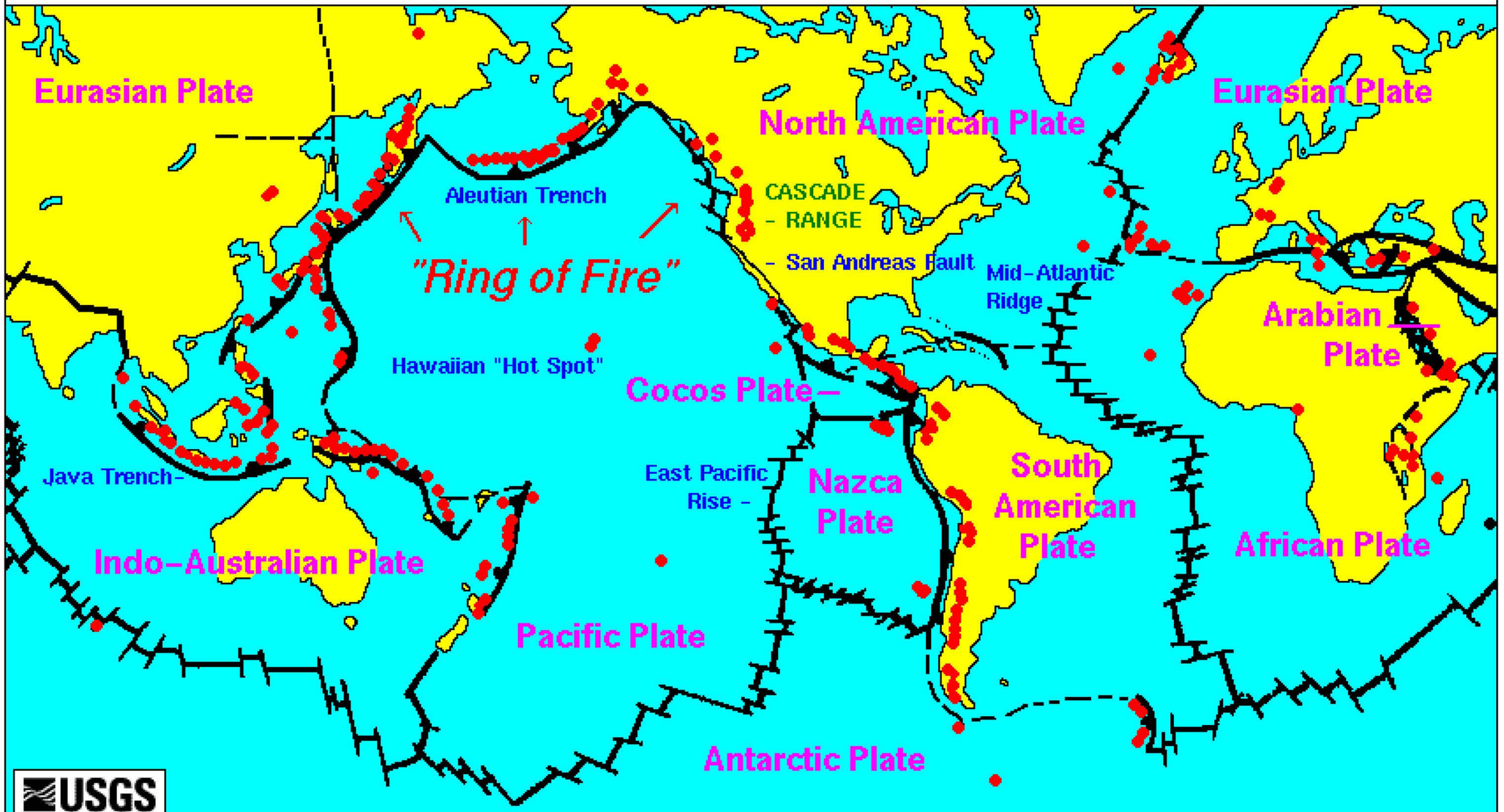
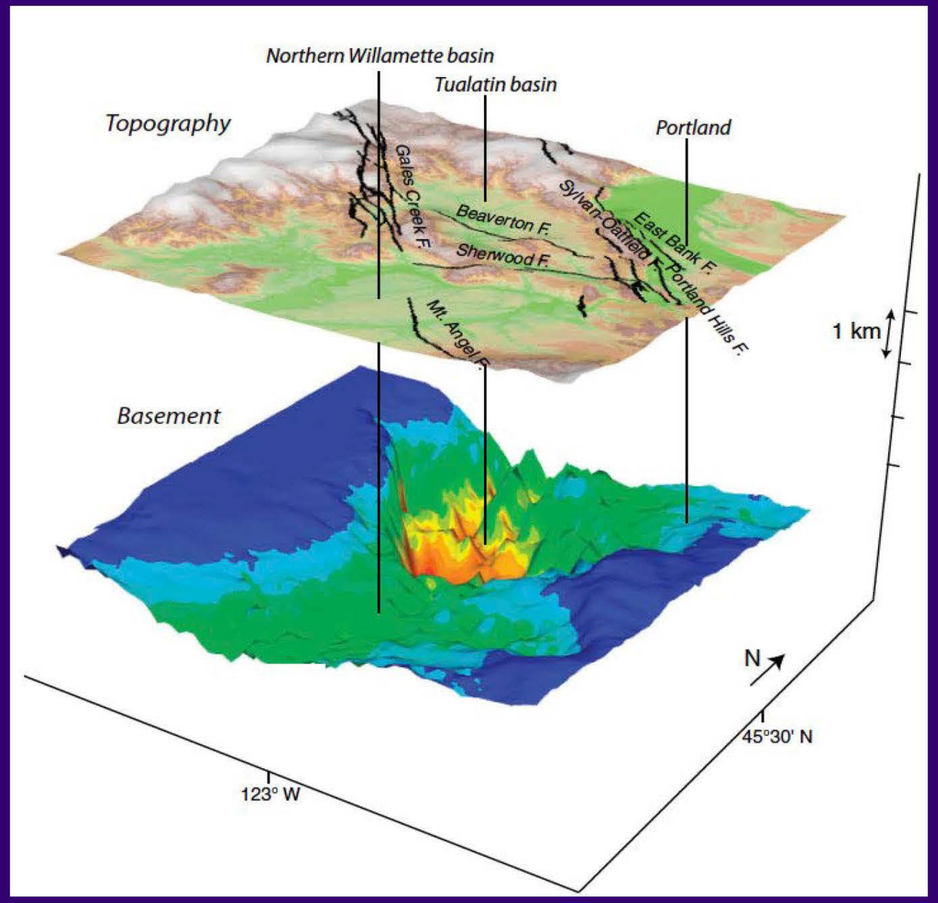
Active Volcanoes, Plate Tectonics, and the "Ring of Fire"



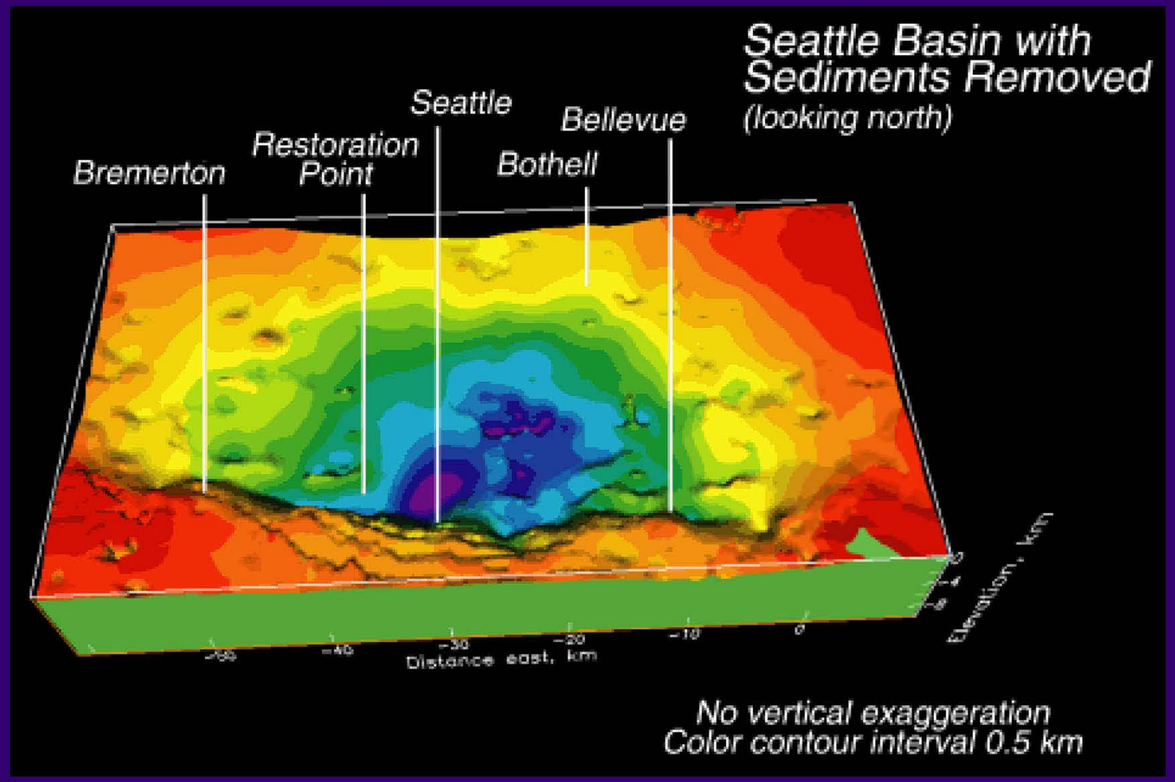
Topinka, USGS/CVO, 1997, Modified from: Tilling, Heliker, and Wright, 1987, and Hamilton, 1976

Portland, OR



McPhee et al. (2014)

Seattle, WA



Blakely et al. (2000)

Today's Discussion

Damage from the 2016 Amatrice Italy Earthquake (Paolo Calvi, UW)

Good Systems: Control Damage

Seismic design force

Resisted by tension and compression in braces

Braces damaged but gravity loads supported

Experiment by:

Andrew Sen (Ph.D. Student)
Charles Roeder (UW)
Dawn Lehman (UW)
Jeff Berman (UW)
K.C. Tsai (NTU)